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INFORMATION CIRCULAR

SOME INSTRUMENTS AND DEVICES THAT COAL-MINE OFFICIALS SHOULD UNDERSTAND AND USE

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U. S. [illegible]

BY

G. W. GROVE

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SOME INSTRUMENTS AND DEVICES THAT COAL-MINE OFFICIALS SHOULD UNDERSTAND AND USE[1]

By G. W. Grove[2]

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INTRODUCTION

Coal-mine officials and those who are preparing to become officials should be familiar with the instruments and devices that are employed rather commonly in and around mines and should know how to use them with safety and efficiency. Among these are instruments and devices used in determining the pressure, velocity, volume, and certain other conditions of ventilation and in detecting the more common mine gases, such as methane, carbon monoxide, and hydrogen sulphide, or a deficiency of that very important agent, oxygen. Water gages, anemometers, barometers, psychrometers, flame safety lamps, lamp-testing boxes, and methane, carbon monoxide, and hydrogen sulphide detectors are described and their use and operation discussed in this paper.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7037."

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Water Gage

A water gage is used for determining differences in pressure or vacuum of ventilating air currents in mines. In its simplest form the water gage is a glass U-tube partly filled with water, both ends of which are open. An extension tube, which may be inserted into a small opening in a partition of the fan house or a stopping between the intake and return airways, is fitted to one end of the U-tube. A scale, graduated in inches or fractions thereof, is attached to the U-tube. Each inch of difference between the height of the water level in one tube and the height of the water level in the other tube gives the water-gage reading, regardless of how the scale is designed to be read.

Another type is the recording water gage, which gives a continuous chart record of the water-gage readings during a 24-hour period. Use of this type is highly desirable, particularly for fan-house installations, as it provides a continuous record of the ventilating pressure.

Much could be said about the importance and meaning of water-gage readings. The pressure registered by a water gage and the volume of air being circulated rather definitely indicate the capacity and condition of mine airways. A mine-ventilating system that requires an abnormally high water gage is generally inefficient and expensive; many persons consider water-gage readings of 5 or more inches as abnormally high.

High blood pressure in the human system is a sign of danger and indicates that the heart is being overworked. Similarly, a high water gage in mine ventilation indicates that too much power is being consumed in driving the mine fan, probably because there are not enough airways, they are inadequate in size, or they are choked with falls; in some cases probably all three of these things are true. Although the water gage generally indicates certain things with respect to the ventilation system, it cannot be depended upon to show everything that is caused by changing conditions. Many mine officials believe that the water gage will indicate all ventilating conditions; however, this is not true. Under some conditions a large fall may completely block an entry or entries or something may occur to "short-circuit" the air completely, yet the water gage will not be affected because the quantity of air flowing may be changed to such an extent that little or no difference will be recorded by the water gage.

It is necessary, also, to consider the amount of air flowing and the amount of power consumed by the fan motor when one interprets the record of the water gage or a change in water-gage readings.

Anemometer

The anemometer is used for measuring the velocity of air currents. The most common type consists of a metal sylindrical frame about 3 or 4 inches in diameter and 1-1/2 to 1-3/4 inches wide, with legs or a base on the bottom so that the instrument will not roll when set down, and a small metal

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loop at the top to serve as a handhold. Within the frame, a number of small arms are attached to a light axle that has a bearing with relatively little friction. Blades are attached to the arms, and the axle, arms, and blades compose what is known as the vane. The blades of the vane are inclined to the plane of revolution and are pitched so that one revolution of the vane indicates an air velocity of 1 foot per minute. At the center of the device, supported by arms attached to the frame, is a graduated dial with a hand or pointer that registers the revolutions of the vane. On the face of the dial is one large circle with 100 divisions, each one of which represents one revolution of the vane, so that one complete revolution of the large dial hand indicates 100 revolutions of the vane, or 100 feet. Within the large circle are small dials with hands. These register 100 feet, 1,000 feet, 10,000 feet, etc., depending on the number of dials. A small catch and lever at the top of the instrument throw the vane into and out of gear, so the dials may be started or stopped at any time while the vane is in motion.

Some anemometers are also provided with a lever attached to the dials, which when operating throws all of the dial settings back to the zero.

When an anemometer is used it should be held or placed in the air current so that the air will flow through the anemometer from the back or side opposite the dials.

To obtain the most accurate reading for practical purposes in mining, the anemometer should be held at arm's length, as nearly perpendicular to the air current as feasible, and moved slowly and regularly up, down, and across the airway, so as to register as nearly as possible the average velocity of the air. It is necessary to move the anemometer to different portions of the airway, as the air velocity is very likely to be greater in the center than near the sides, top, and bottom.

Although the method just described gives the most nearly accurate average results, if "check" readings are to be made periodically in the same airway, the most accurate comparison can be made by placing the anemometer in a definite spot in the airway and taking the daily, weekly, or other periodic reading at the same place.

To take a reading, the anemometer should be held or placed in the air current, as described, the lever that operates the dial mechanism should be pushed into gear or to the "on" position, which starts the dial hands; the time should be noted carefully; and at the end of one or more minutes the lever should be pushed to the "off" position to stop the dial hands.

After the velocity of the air current has been determined as above it should be multiplied by the area or cross section of the airway to determine the number of cubic feet of air flowing in the airway. For example, if the anemometer shows 300 feet velocity per minute in an airway 6 feet high and 10 feet wide, the amount of air passing the point at which the reading was taken will be 300 x 60 (6 x 10 area), or 18,000 cubic feet per minute. More accurate readings may be obtained by adding or subtracting certain constants or correction factors furnished by the maker for each anemometer. These correction factors, however, usually are of minor importance, as at best the

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anemometer only roughly approximates the average velocity of an air current, owing to fluctuation of air current, variation in velocity in different portions of the airway, and variations in time and place of taking readings.

Usually, an anemometer will not function when the air velocity is under 30 feet per minute, and readings under 80 to 100 feet generally are subject to correction and are likely to be erroneous.

Other types of anemometers are obtainable, but the type and method described are used most generally.

Barometer

Atmospheric pressure is measured by the barometer. There are two kinds of barometers, mercuric and aneroid, the latter being used most commonly in or around mines.

Mercuric barometer. - The mercuric barometer is a glass tube about 3 feet long, closed at one end, and filled with mercury. The mercury is held in the tube while the latter is inverted and the open end submerged in a cup or vessel containing mercury. The tube is then supported in an upright position. The mercury will then drop in the tube until the distance from the top of the mercury in the tube to the surface of the mercury in the cup is about 30 inches at or around sea level.

There is essentially a vacuum in the space above the mercury in the closed end of the tube; therefore, the force that holds up the 30-inch column of mercury is the pressure of the atmosphere. The height of the mercury column will vary as the atmospheric pressure changes with respect to height above or below sea level and as to the density or weight of the air; consequently, an increase in atmospheric pressure will cause the height of the mercury column to be greater, and a decrease in atmospheric pressure will cause the reverse to be true. Changes in atmospheric pressure may be caused by a difference in altitude or in weather conditions. At sea level the barometer may register 29 to 31 inches, depending on the temperature, humidity, and density of the air; but normally the sea-level reading of a barometer is about 29.92 inches and is about 24.89 inches at an altitude of 5,000 feet above sea level.

A cubic inch of mercury weighs 0.49 pound; therefore, a column of mercury 1 inch high exerts a pressure of 0.49 pound per square inch, and a column 30 inches high exerts a pressure of 30 x 0.49, or 14.7 pounds per square inch, which is held up by the atmospheric pressure; this is taken as the standard for atmospheric pressure at sea level when the mercuric barometer stands at about 30 inches and the temperature is 60° F. and is known as one atmosphere. Under these conditions, a cubic foot of air weighs 0.0765 pound.

Aneroid barometer. - The aneroid barometer comprises a metal case about the size and shape of a large thick watch, from which the air has bee

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removed, with the face graduated to a scale ranging from about 25 to 31, to correspond to inches of mercury. The back is made of thin, elastic metal. The back cover springs outward as the atmospheric pressure decreases and bends inward as the pressure increases. This movement is very slight, but it is multiplied by the mechanism of the barometer and transmitted to a pointer or hand that moves along the scale and indicates the atmospheric pressure. Aneroid barometers should be compared frequently with a mercuric barometer and regulated if necessary.

Recording barometers. - Recording barometers of the aneroid type are obtainable and should be used where a continuous record of atmospheric pressure is desired. In mining operations the barometer is used in connection with the liberation of gas.

Storm or other atmospheric conditions, accompanied by a lowering of the air pressure or atmospheric pressure outside of a mine, as indicated by a "falling" or a "low" barometer, tend to cause methane to be liberated more freely. Such conditions also may release gas that is being held on gobs or behind leaky stoppings of imperfectly sealed regions by the ventilating pressure and allow it to enter active workings. A sudden falling of the barometer indicates particularly dangerous conditions of possible hazards from a greater inflow of gas into the mine openings, and this danger is greatest adjacent to open, poorly ventilated, abandoned regions or to sealed regions where the pillars are shattered or the seals are imperfectly made or maintained. A barometer, therefore, is a useful and valuable piece of equipment at a mine and should be read frequently; precautionary measures should be taken promptly when the barometer changes suddenly.

Psychrometer

The psychrometer (sometimes called hygrometer) is used to determine the percentage or degree of saturation of the air by moisture.

The amount of moisture or water carried into or out of the mine by the ventilating current can be determined from certain tables or charts (obtainable from the United States Weather Bureau when the anemometer and psychrometer readings are known). The relative saturation or humidity of the air is the amount of moisture the air is carrying at its temperature in proportion to all of the moisture it could hold at that temperature. To prevent explosions, it is important to know the relative saturation of the mine air as it indicates whether coal dust in a mine is being dried or being moistened by the ventilating air current.

The sling psychrometer is the type commonly used in mines; the type used by the Federal Bureau of Mines consists of two high-grade mercuric thermometers, graduated alike (Fahrenheit scale), fastened side by side on a light metal frame. A handle is attached to the frame by a swivel so that the device can be whirled in the air. The bulb of one of the thermometers (known as the wet bulb) is covered with a small muslin sack. To take a reading, the psychrometer, with the sack of the wet bulb thoroughly wetted, the uncovered bulb being dry, is whirled rapidly in the air for one or more minutes and then the thermometers are read as quickly as possible. If the

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air is comparatively dry, evaporation of moisture on the wet bulb is rapid; evaporation is a cooling process, and the mercury column in the wet-bulb thermometer drops while that in the dry-bulb thermometer records the temperature of the atmosphere in which the bulb was whirled, with resultant considerable difference in the reading of the two thermometers.

On the other hand, if the air is almost or completely saturated with moisture, whirling the psychrometer in the air will cause little or none of the moisture on the wet bulb to evaporate, and there will be little or no difference in the readings of the two thermometers. The readings of the thermometers (the difference in which is sometimes termed the depression) should be compared to determine the relative humidity or saturation of the air, the value of which corresponds to the number on the psychrometric charts or tables.

Cold air does not contain and will not absorb as much moisture as warm air; if the temperature of air is increased it will absorb additional moisture, and if decreased it will release or deposit moisture. This explains why mines and coal dust are dry during cold weather and moisture is present and so-called "sweating" occurs in mines during warm weather.

The amount of moisture or water that can be carried into or out of a mine by the ventilating current as a result of increasing or decreasing the temperature of the intake air is surprising. Air at 30° F. can retain or carry, if completely saturated, only about 3.4 gallons of water per 100,000 cubic feet of air, whereas air at 60° F. (about normal temperature for many mines) can retain or carry approximately 10 gallons of water per 100,000 cubic feet of air, a difference of 6.6 gallons of water for each 100,000 cub feet of air.

For example, if on a fairly cold day the outside temperature averages 30° F., and the air that enters the mine is 50-percent saturated (a fairly normal condition) with moisture, about 1.7 gallons of water per 100,000 cubic feet of air will be carried into the mine. If the air as it travels through the mine increases in temperature to 60° F., and it takes up moisture until it is 90-percent saturated (not an unusual amount), it will contain about 11 gallons of water per 100,000 cubic feet of air. This is a difference of approximately 9.3 gallons of water per 100,000 cubic feet of air which represents the amount of water being carried out of the mine per minute by each 100,000 cubic feet of air, or a total of 13,492 gallons in 24 hours (1,440 x 9.3) per 100,000 cubic feet of air.

In addition to the effect of relative humidity or moisture saturation on the physical condition of a mine, it has a decided bearing on the comfor health, and efficiency of the workmen employed in a mine. Therefore, as an instrument for indicating the prevailing conditions with respect to moistur in the air, the psychrometer should be more completely and generally understood and much more frequently used.

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DEVICES FOR DETECTING GASES IN MINE AIR

Flame Safety Lamp[3]

The flame safety lamp, which furnishes a limited amount of illumination, is used primarily for detecting methane gas and indicating a deficiency of oxygen in the atmosphere.

The original flame safety lamp was introduced into coal mines over 100 years ago as a relatively safe means of general illumination. However, during recent years it has been largely replaced for this purpose by the more efficient electric lamp, and it is now used in the United States largely to detect gas.

Two types of flame safety lamp (Wolf and Koehler) are used almost exclusively in the United States. These lamps are in too common use to require description. The Bureau of Mines has tested and approved as permissible several models of these two types. Permissible lamps should be used exclusively, as they have certain safety features that nonpermissible lamps do not have.

It is believed that mining men in general do not realize that the reduction of oxygen below normal (20.93) will affect materially the efficiency of gas testing with a flame safety lamp, because the lower oxygen rapidly affects the illuminating power and consequently the heat of the flame.

Tests conducted by the Bureau of Mines[4] show that the effect of the reduction of oxygen on the illuminating power (size and color of flame) of a flame safety lamp is as follows:

Oxygen, percent	Illumination, percent	Oxygen, percent	Illumination, percent
20.93	100	19.30	40
20.70	90	18.90	28
20.30	75	18.30	12
19.90	70		

A further reduction in oxygen to about 16 percent extinguishes the lamp, and illumination, of course, drops to zero. Other tests made by the Bureau[5] show that, irrespective of the amount of methane present, a flame safety lamp is extinguished when the oxygen content falls below 13 percent, indicating that if enough methane is present the lamp will burn in an atmosphere containing about 3 percent less oxygen than it would require otherwise. The presence of methane is indicated by a flame safety lamp because

3/ Forbes, J. J., and Grove, G. W., Mine Gases and Means for Their Detection: Miners' Circular 33, Bureau of Mines, 1937. This circular describes in greater detail flame safety lamps and other gas-detecting devices.

4/ Burrell, G.A., Chart of Properties of Mine Gases: Bureau of Mines,1918.

5/ Hooker, A. B., Coggeshall, E. J., and Jones, G. W., Behavior of Flame Safety Lamps in Mine Atmospheres Deficient in Osygen: Rep. of Investigations 3327, Bureau of Mines, 1937, 6 pp.

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the gas is burned with "elongation" when the flame is high and a "cap" when it is low. Since a reduction of oxygen below normal has the effect of decreasing the illumination capabilities of the lamp, and as illumination is due to the heat of the flame, a reduction of illumination or heat keeps methane from burning normally and interferes seriously with the dependability of the lamp in the detection of gas; hence, the flame safety lamp at best gives but a rough estimate of the explosive-gas content or percentage of the surrounding air.

A flame safety lamp will burn feebly when 15.6 percent of oxygen and 7.1 percent of methane are present in the atmosphere, but no "cap" can be observed even though the amount of methane present considerably exceeds the explosive minimum. However, the presence of an explosive mixture is proved by the fact that, after the lamp has been extinguished, when the igniter is used an explosion occurs immediately inside of the lamp, because the igniter spark, which does not depend on oxygen for its heat, is of normal temperature and volume.

In view of the rapidity with which illumination decreases with a slight reduction in oxygen, and the consequent reduction in the gas-detecting ability of the lamp, it is obvious that a flame safety lamp will be anything but efficient for detecting methane where oxygen is appreciably deficient. It is believed that the flame safety lamp cannot be relied upon to detect methane efficiently when less than 20 percent of oxygen is present, as at this point the flame will have lost about 30 percent of its heat and illuminating power.

It is fairly certain that a flame safety lamp cannot detect efficiently the presence of methane when the oxygen content drops to 19 percent, because approximately 70 percent of the heat and illumination has been destroyed; hence, with less than 19 percent of oxygen present, the flame safety lamp has relatively little if any value in detecting methane.

Even under normal conditions, the ordinary flame safety lamp, although widely used, is not an extremely sensitive or accurate gas-detecting device. Attachments that have been developed by the Electrical Section of the Bureau of Mines to increase the sensitivity of flame safety lamps are being used to some extent. However, if sensitivity and accuracy with low percentages are desired, an electric methane detector should be employed or the mine air should be sampled and analyzed.

Lamp-testing box. - A lamp-testing box is a device for testing a flame safety lamp after it is completely assembled and ready for use. The usual method of testing is to blow around the bottom inlet ring and around the top and bottom of the glass; such a test, however, may not disclose defective parts or improper assembly.

Although various lamp-testing boxes have been designed and used, the type in which an unlighted lamp can be placed in an explosive mixture of gas and the igniter then operated provides the severest test. A lamp-testing

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box of this type consists of a tight wooden box large enough to hold a lamp and provided with a paper diaphragm on top, for release of pressure in the event of an explosion, and a door having a glass center. The box also is equipped to take in a supply of gas and has a small fan (either hand or motor operated) for diffusing gas and forcing it inside of the lamp and a device for operating the igniter of the lamp from outside the box. Gases, such as natural gas from a gas line, methane, butane, and propane from cylinders, and liquid amoline and gasoline vapors can be used for making tests.

To make a test, an unlighted lamp is placed in the box; the paper diaphragm in the top of the box and the door of the box are closed tightly; a predetermined amount of gas (depending on the type of gas being used) is introduced into the box; the gas is mixed thoroughly and forced into the lamp; and, finally, the igniter is turned. If an explosive mixture of gas has been introduced into the box and also into the lamp, turning the igniter will result in an explosion inside the lamp and cause pressure to form there. However, if the lamp is in good condition and properly assembled, the explosion will be confined to the inside of the lamp. On the other hand, if the lamp is defective, the flame of the explosion will be driven to the outside of the lamp and will ignite and explode the gas surrounding the lamp.

Methane Detectors

A methane detector is used for detecting and registering the percentage of methane gas present in air. Although several types have been developed and four have been tested and approved by the Bureau of Mines, only the two (U.C.C. and M.S.A.) used most commonly will be considered. Both of these detectors are of the electrical type and are based on a modified "Wheatstone bridge", which, roughly, consists of two or more balanced electrical circuits.

The burning of methane by an electric filament in one of the circuits sets up increased resistance which unbalances the circuits. The amount of resistance or lack of balance resulting from the burning of methane is indicated, in turn, in percentage of methane on a graduated meter scale.

An electric current from a small storage battery is turned on the detector, the meter hands are set at zero, and the detector is taken to the place where the test is to be made. With the U.C.C. type, the detector head containing the filament is placed at the point where the test is to be made; with the M.S.A. type, the air to be tested is drawn through the detector by an aspirator bulb. If methane is present it will be indicated on the meter scale. Both types can be set at zero in an atmosphere containing methane. "Check" readings and settings must be made rather frequently to compensate for a drop in battery voltage. An electric cap lamp is provided with each detector and is supplied with current by the battery that furnishes energy for the detector. A flame safety lamp will not detect low percentages of methane; therefore, an electric methane detector is highly desirable for testing return air currents and making ventilation surveys.

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Carbon Monixide Detector

A carbon monoxide detector is a device for detecting and indicating the approximate percentage of carbon monoxide. As carbon monoxide is an extremely deadly gas and one very likely to be found in connection with mine fires or blasting in mines or after mine explosions, detection of small percentages following mine fires, blasting, and explosions is of vital importance.

The detector used most commonly is known as the hoolamite or iodine pentoxide detector. It is a short metal barrel containing an inlet valve through which air is drawn by a rubber aspirator bulb. When the aspirator bulb is squeezed, air is forced through an outlet valve and a metal tube that connects with another larger metal barrel containing gasorbent for absorbing interfering gases, and thence out through a small glass tube filled with a material called hoolamite on granules of pumice stone. A color scale ranging from 0.10 to 1 percent is attached to the detector alongside the hoolamite tube.

To use the detector, the ends of a hoolamite tube are broken off and the tube is placed in the detector. The detector bulb is then squeezed 10 times and the color of the tube is matched with the color scale. If the color in the detector tube has changed, the percentage of carbon monoxide present is estimated. In the presence of carbon monoxide, the chemical hoolamite or iodine pentoxide ($I_2O_5 + H_2SO_4 + SO_3$) liberates iodine, the reaction changing the color in the detector tube from grayish (the original color of the chemical) to a light green or dark green color, depending on the amount of carbon monoxide present. If no color change is visible after 10 squeezes, the tube should be squeezed again 10 times.

When in good condition, the detector is fairly accurate and will detect consistently 0.07 to 0.10 percent of carbon monoxide; however, the detector must be assembled and used carefully or the results may not be satisfactory.

Hydrogen Sulphide Detector

Although hydrogen sulphide gas is rather rare in coal mines, it is encountered occasionally. Hydrogen sulphide is an extremely dangerous gas and, as the detector is fairly new, a description of it is included because hydrogen sulphide gas does at times occur in coal mines, chiefly along with water flows or under some circumstances in connection with blasting.

The detector consists of a small inlet metal barrel and an outlet barrel to which is attached a rubber aspirator bulb with inlet and outlet valves, a movable scale, and a glass tube containing a white granular chemical. The chemical used in the detector tube is silver nitrate and sodium cyanide ($AgNo_3 + NaCN$) on activated alumina (Al_2O_3). The latter serves as a carrier for the silver nitrate and sodium cyanide, similar to the pumice used in the carbon monoxide detector.

To use the detector, the ends of a sealed detector tube are broken off and the tube is inserted between the inlet barrel and the outlet barrel of

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the detector. The scale is then placed so that zero on the scale is in alinement with the beginning of the chemical granules of the tube and it is tightened in this position; the aspirator bulb is squeezed 10 times, and the percentage of hydrogen sulphide is read on the scale midway between the longest and shortest ends of the gray discoloration of the detector tube.

The action of hydrogen sulphide on the detector tube differs from that of carbon monoxide on the carbon monoxide detector; the chemical in the hydrogen sulphide detector is discolored for a definite distance only, depending on percentage, whereas in the carbon monoxide detector the discoloration occurs throughout the tube.

The hydrogen sulphide detector is very sensitive and indicates definately the presence of 0.0025 percent or more of hydrogen sulphide.

In addition to the instruments and devices discussed, there are others that a mine official should use, but those described are believed to be the most important.

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